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STUDY OF THE CONTROL OF PERMEABILITY OF NYLON PARACHUTE CLOTH AT HIGH AND LOW DIFFERENTIAL PRESSURES

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WRIGHT AIR DEVELOPMENT CENTER

WADC TECHNICAL REPORT 54-468

STUDY OF THE CONTROL OF PERMEABILITY OF NYLON PARACHUTE CLOTH AT HIGH AND LOW DIFFERENTIAL PRESSURES

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MARCH 1955

MATERIALS LABORATORY
CONTRACT No. AF 33(600)-26109
PROJECT No. 7320

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
500 - 29 September 1955

FOREWORD

This report was prepared by the Cheney Brothers Company under USAF Contract No. AF 33(600)-26109. The contract was initiated under Project No. 7320, "Air Force Textile Materials", Task No. 73201, "Textiles Materials for Parachutes", formerly RDO No. 612-12, "Textiles for High Speed Parachutes", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Miss Joyce C. McGrath acting as project engineer.

The work reported herein covers the period from September 1953 to November 1954.

ABSTRACT

Twenty-four differently constructed samples of nylon cloth in the desired weight range were woven, finished and tested.

A special mathematical study of the relationship between air permeability at 1/2 inch of water pressure differential and at higher pressure differentials was made. This discloses that a linear relationship in these values exists when plotted on full logarithmic graph paper.

The ability of the cloth manufacturer to vary the high pressure differential permeability, while retaining fixed low pressure permeability ranges, is indicated to be a practical one within limits.

A total of 1000 yards of additional cloth duplicating two of the twenty-four constructions as selected by the Air Force was supplied for use in further evaluation of the material by the Parachute Branch of Equipment Laboratory.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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INTRODUCTION

Relatively little data are available to indicate whether or not the air permeability characteristics at increased pressure differentials for a given construction of parachute fabric may be varied independently of the air permeability characteristics at the 1/2-inch pressure differential. If it is determined that a fabric manufacturer can control these properties independently, it may prove to be possible to develop a fabric which will provide the parachute designer with a selection of properties which will enable him to achieve improved parachute performance.

It is therefore the objective of this contract to obtain basic information as to how the permeabilities, at high and low pressures, of a given nylon fabric could be independently controlled.

SECTION I

PROCEDURE

For purposes of this study, one type of fabric was investigated, namely the fabric described by Specification MIL-C-7350, Type I, 2.25-oz. Nylon Cargo Paracnute Fabric. Fabric to this specification has been used in certain cargo parachutes of large dimensions, such as the No. G-12. Under this experimental contract, 24 variations of the basic fabric were woven as follows:

Yarn: 100/34, Type 300, High Tenacity Nylon
Twist as noted below

Warp: 64 Ends/inch, 42.2 inches wide - in reed

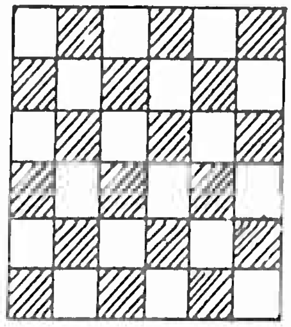
Filling: 68 Picks/inch off loom

Code No.	Nominal Twist/Inch (Z) Warp	Filling	Weave	Finish
1N	0.75	0.75	Plain	Not calendered
2N	0.75	0.75	Twill(2x1)	" "
3N	0.75	0.75	Dobby	" "
4N	0.75	5.75	Plain	" "
5N	0.75	5.75	Twill(2x1)	" "
6N	0.75	5.75	Dobby	" "
1C	0.75	0.75	Plain	Calendered in grey
2C	0.75	0.75	Twill(2x1)	" " "
3C	0.75	0.75	Dobby	" " "
4C	0.75	5.75	Plain	" " "
5C	0.75	5.75	Twill(2x1)	" " "
6C	0.75	5.75	Dobby	" " "
7N	5.75	0.75	Plain	Not calendered
8N	5.75	0.75	Twill(2x1)	" "
9N	5.75	0.75	Dobby	" "
10N	5.75	5.75	Plain	" "
11N	5.75	5.75	Twill(2x1)	" "
12N	5.75	5.75	Dobby	" "
7C	5.75	0.75	Plain	Calendered in grey
8C	5.75	0.75	Twill(2x1)	" " "
9C	5.75	0.75	Dobby	" " "
10C	5.75	5.75	Plain	" " "
11C	5.75	5.75	Twill(2x1)	" " "
12C	5.75	5.75	Dobby	" " "

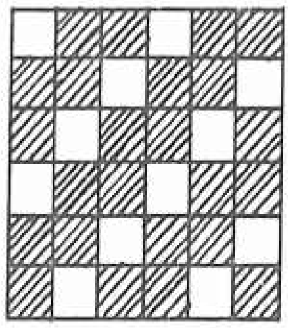
Note: The dobby weave used is that shown in Specification MIL-C-7350, Type I, Weave Diagram (See Graph 1).

GRAPH 1

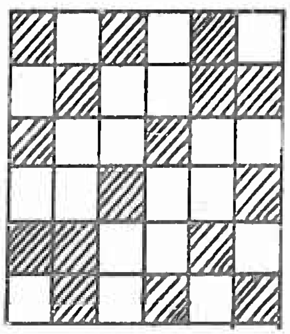
WEAVE DIAGRAMS



Plain Weave



2x1 Twill



Dobby

A. WEAVING OF SAMPLES

A 500-yard warp was made using the 100/34/.75-Z yarn and 40 yards each of Code Nos. 1 through 6 were woven in succession, this yardage to be finished as Code Nos. 1N through 6N. Another 40 yards each of Code Nos. 1 through 6 were then woven, to be finished as Code Nos. 1C through 6C.

A second 500-yard warp was made with the 100/34/5.75-Z yarn and 40 yards each of Code Nos. 7 through 12 were woven, to be finished as Code Nos. 7N through 12N. Another 40 yards each of Code Nos. 7 through 12 were then woven, to be finished as Code Nos. 7C through 12C.

B. FINISHING OF SAMPLES

The samples bearing the Code Nos. 1C through 12C were given a hot calendering in the grey, two nips, approximately seven tons pressure. A Van Vlaanderen calender with one steam heated steel roll and two wool-felt paper filled rolls was used.

Samples 1C through 12C were then sewn to samples 1N through 12N and processed in one lot as follows:

Jig scour, four ends at the boil

3.0 lbs. Naccanol NR (National Aniline & Chemical Co.)
2.0 lbs. Caustic Flakes
1.0 lb. Tripolyphosphate

100 gallons of water

Rinse, in the jig, three ends at the boil

4.0 lbs. Boric Acid

100 gallons of water

Flat extraction on a vacuum extractor

Pad through a solution of one quart of "Coronyl" oil (E. F. Drew & Co.) in ten gallons of water and dry at 275-300°F. in the crepe dryer.

Steam tenter to width.

C. FURNISHING CLOTH FOR PARACHUTE EVALUATION

After reviewing the results obtained on the 24 samples, the Materials Laboratory requested reproduction under Item VI of the contract as follows:

750 yards Code 4C (Reproduction Code No. R4C)
250 yards Code 2C (Reproduction Code No. R2C)

In addition, a Local Purchase Branch order, Contract AF-33(616)-3547, was issued for:

500 yards Code 1C (Reproduction Code No. R1C)
250 yards Code 4C (Reproduction Code No. R4C)

D. WEAVING OF REPRODUCTION LOTS

A 2100-yard warp of 100/34/.75-Z, Type 300, Nylon, corresponding to the one used to manufacture the samples identified as Code Nos. 1, 2, and 4, was made and woven out in approximately 260-yard grey pieces as follows:

Code R1C	520 yards
Code R2C	260 yards
Code R4C	1,112 yards

E. FINISHING OF REPRODUCTION LOTS

The 1892 yards of grey fabric were processed in one lot, including hot calendering in the grey, as outlined under "B. FINISHING OF SAMPLES."

The Code R1C fabric showed permeability results (TABLE VII) close to those obtained in the Wright Air Development Center Materials Laboratory tests shown in TABLE V.

The Code R2C fabric had a permeability in initial tests of 33.3 cu ft/min/sq ft at 1/2-inch pressure and 265 cu ft/min/sq ft at 12 inches of pressure, which was somewhat higher than the permeability previously reported in TABLE V (1/2-inch - 26.5; 12-inch - 228.9), so we were requested by the Materials Laboratory to reduce the 1/2-inch pressure permeability to 26 cu ft/min/sq ft. The cloth was again hot calendered and rope washed at 120°F in plain water and steam tentered. The outcome was a permeability of 29.4 cu ft/min/sq ft at 1/2-inch pressure and 275 cu ft/min/sq ft at 12-inch pressure as shown in TABLE VII. The cloth was then shipped without further reprocessing.

The Code R4C fabric had an initial porosity of 44.6 cu ft/min/sq ft at 1/2-inch pressure and 312 cu ft/min/sq ft at 12-inch pressure, slightly below the results obtained on Code 4C sample, as shown in TABLE V (1/2-inch - 55; 12-inch - 385). In an effort to raise the permeability to the desired level, one piece from this lot was rope washed, relaxed, on a reel, but showed no apparent permeability change. The remainder of the lot was not rehandled. Permeability tests on two pieces from this lot are shown in TABLE VII.

Under Item VI of this contract, we shipped:

238-4/8	yards	- Code R2C
804	yards	- Code R4C
1042-4/8	yards	

Against Contract AF-33(616)-3547, we shipped:

481-6/8	yards	- Code R1C
250-7/8	yards	- Code R4C
732-5/8	yards	

F. TESTING

Physical and chemical tests on the samples were made in accordance with Specification MIL-C-7350A, Amendment 1, Type I fabric. These tests (as applicable) were performed on grey goods (See TABLE I) and on finished goods (See TABLE II).

Seam efficiency tests on the 24 samples are reported in TABLE II.

Physical and chemical tests on the reproduction lots are reported in TABLE III.

TABLE IV lists Cheney Brothers' permeability test results on the 24 samples, tested over a pressure range of 1/2 inch through 12 inches of water (limit of contractor's equipment - United States Testing Company air permeability tester on which we changed the sample area from 6 sq in. to 1 or 2 sq in. as required by permeability range of the sample. The manometer which measures pressure drop across the fabric was changed by using a "U" tube filled with water instead of the manometer supplied by the manufacturer, which read to only a 1-inch pressure drop.)

TABLE V lists Wright Air Development Center Materials Laboratory permeability figures over a pressure range of 1 to 20 inches for the same marked areas as tested by Cheney Brothers and reported in TABLE IV. These tests were made on the Wright Air Development Center Frazier high pressure differential permeability tester, which has a range of 1 to 20 inches of water on 1 sq in. of fabric.

The permeability figures given in TABLE VI are an average of five readings on each sample over the 1 to 20-inch range made by Wright Air Development Center. These tests were made on the 25-yard samples submitted of each of the 24 fabrics. All conclusions drawn from this work are based on these figures.

TABLE VII lists the permeability readings over the 1/2-inch to 12-inch range obtained by Cheney Brothers on the reproduction lots.

TABLE I

PHYSICAL TESTS ON GREIGE CLOTH

Code No.	Weave	Twist per Inch Nominal (Z) Warp	Twist per Inch Nominal (Z) Fill.	Air Permeability ($Ft.^3$/ $Min./Ft.^2$)**	Width Inches	Thickness (Inches)	Thread Count (Thds./In.) Warp*	Thread Count (Thds./In.) Fill.*
1N	Plain	3/4	3/4	85	40	.0049	68	68
2N	Twill	3/4	3/4	90	40-1/4	.0054	67	68
3N	Dobby	3/4	3/4	103	40-3/4	.0050	66	67
4N	Plain	3/4	5-3/4	161	40-1/8	.0053	67	68
5N	Twill	3/4	5-3/4	214	40-3/8	.0057	67	68
6N	Dobby	3/4	5-3/4	205	40-3/[illegible]	.0057	67	68
7N	Plain	5-3/4	3/4	92	39-3/4	.0053	68	68
8N	Twill	5-3/4	3/4	144	40	.0060	68	68
9N	Dobby	5-3/4	3/4	155	40-1/4	.0060	67	67
10N	Plain	5-3/4	5-3/4	200	39-3/8	.0058	68	68
11N	Twill	5-3/4	5-3/4	284	39-5/8	.0064	68	68
12N	Dobby	5-3/4	5-3/4	321	39-5/8	.0065	68	67
1C	Plain	3/4	3/4	79	40-3/8	.0047	67	68
2C	Twill	3/4	3/4	106	41	.0057	66	68
3C	Dobby	3/4	3/4	107	40-1/2	.0051	66	68
4C	Plain	3/4	5-3/4	169	40	.0052	68	68
5C	Twill	3/4	5-3/4	206	40-3/4	.0060	66	68
6C	Dobby	3/4	5-3/4	204	40-3/8	.0058	67	67
7C	Plain	5-3/4	3/4	124	39-1/2	.0053	68	68
8C	Twill	5-3/4	3/4	143	40-1/4	.0060	67	67
9C	Dobby	5-3/4	3/4	140	40-1/4	.0061	67	68
10C	Plain	5-3/4	5-3/4	212	39-1/4	.0057	68	68
11C	Twill	5-3/4	5-3/4	290	39-1/2	.0066	68	68
12C	Dobby	5-3/4	5-3/4	282	40	.0064	68	67

*Nominal Thread Count, 68 x 68 on all samples.
**1/2" H_2O Dif.

TABLE II

PHYSICAL TESTS ON FINISHED CLOTH
(Sample Lots)

Code No.	Weave	Actual Twist/Inch (Z) Warp	Fill.	Width Inches	Thread Count (Thds./In.) Warp	Fill.	Weight (Ozs./Sq.Yd.)	Strip Breaking Strength (Lbs./In.) Warp	Fill.	Elongation % Warp	Fill.	Tongue Tearing Strength (Lbs.) Warp	Fill.
1-N	Plain	.9	1.2	37-1/8	73	73	2.10	106.4	105.8	27	33	13.1	13.9
2-N	Twill	.8	1.2	37-1/2	72	71	2.02	107.8	107.0	27	34	18.4	16.5
3-N	Dobby	.9	.9	37-1/4	72	71	2.02	109.0	105.0	31	35	16.9	16.8
4-N	Plain	.8	6.0	37	73	73	2.05	106.0	106.6	30	34	13.6	13.3
5-N	Twill	.8	5.9	37-1/8	72	71	2.00	107.2	106.0	28	36	18.0	16.7
6-N	Dobby	.9	6.2	37-1/8	73	72	2.01	109.0	107.0	32	35	15.8	16.9
7-N	Plain	6.0	1.3	36-3/8	74	70	2.08	110.0	102.6	27	37	12.8	12.8
8-N	Twill	6.0	1.1	37-1/8	73	72	2.03	108.2	105.0	30	36	18.6	17.2
9-N	Dobby	6.3	1.2	36-1/2	74	71	2.02	110.6	104.4	28	36	16.3	16.3
10-N	Plain	6.0	6.5	36-1/8	74	71	2.10	110.4	103.0	28	39	12.2	13.7
11-N	Twill	6.3	6.5	36-1/2	74	71	2.06	110.0	105.0	28	38	18.3	17.4
12-N	Dobby	6.2	6.2	36-1/4	74	71	2.08	109.2	103.2	30	39	15.6	16.6
1-C	Plain	1.2	1.2	36-7/8	73	72	2.10	107.0	101.6	28	35	12.8	12.7
2-C	Twill	.7	1.2	37-1/2	72	72	2.02	109.0	100.0	30	33	19.0	15.2
3-C	Dobby	.8	1.3	37-1/4	72	71	2.01	107.2	103.0	33	39	16.2	15.4
4-C	Plain	1.0	6.7	36-7/8	73	72	2.16	109.0	108.6	27	35	13.6	13.5
5-C	Twill	.7	6.2	37	73	71	2.10	108.2	103.8	30	34	16.7	17.7
6-C	Dobby	.8	6.5	37	73	72	2.02	108.6	106.0	31	34	16.6	17.0
7-C	Plain	5.8	1.3	36-1/2	74	72	2.16	109.4	103.0	31	37	13.5	12.8
8-C	Twill	6.3	1.4	36-3/4	73	71	2.04	113.2	107.0	29	36	19.5	17.1
9-C	Dobby	6.0	1.2	36-3/4	73	72	2.03	108.8	101.0	31	35	17.7	17.3
10-C	Plain	6.2	6.4	36-1/8	75	72	2.16	110.0	103.6	30	37	12.3	13.5
11-C	Twill	6.0	6.5	36-1/2	74	72	2.04	112.2	107.4	29	37	19.6	17.8
12-C	Dobby	6.2	6.5	36-1/2	74	70	2.08	112.4	103.2	29	37	16.4	16.7

TABLE II continued

PHYSICAL TESTS ON FINISHED CLOTH
(Sample Lots)

SEAM EFFICIENCY TESTS (Average of 5 Tests)

Code No.	Tensile Lbs. (Grab Method) Cloth	Seam	Seam Efficiency - %
1N	138.4	99.2	71.8
2N	133.8	112.4	84.0
3N	138.0	98.4	71.4
4N	138.8	97.0	69.8
5N	131.2	94.8	72.2
6N	135.8	103.2	76.0
7N	142.2	100.8	70.8
8N	131.8	91.4	69.2
9N	132.6	97.6	73.8
10N	137.2	82.8	60.2
11N	140.4	84.8	60.6
12N	127.4	91.0	71.4
1C	143.2	97.0	67.6
2C	129.2	109.4	84.6
3C	133.6	102.6	76.6
4C	142.6	94.4	66.2
5C	130.4	95.2	73.0
6C	140.8	94.0	66.4
7C	146.0	96.8	66.4
8C	130.8	99.2	75.8
9C	137.4	99.6	72.6
10C	130.0	92.0	70.8
11C	131.4	85.0	64.8
12C	130.2	97.6	75.0

Method 5110 of CCC-T-191b, except seams were made using standard nylon cargo seam; 10 stitches per inch, 2-needle machine, "E" nylon sewing thread. Samples were sewed with two selvages in seam.

TABLE III

PHYSICAL TESTS ON FINISHED CLOTH

REPRODUCTION LOTS

Code No.	Weave	Actual Twist/Inch (Z) Warp	Fill.	Width-Inches	Thread Count (Thds./In.) Warp	Fill.	Weight (Ozs./Sq.Yd.)	Strip Breaking Strength (Lbs./In.) Warp	Fill.	Elongation % Warp	Fill.	Tongue Tearing Strength (Lbs.) Warp	Fill.
R1C	Plain	0.55	1.3	37-1/4	72	71	2.07	105.0	103.4	29	31	12.8	14.0
R2C	Twill	0.72	1.15	37-1/2	72	72	2.02	103.0	101.2	31	32	18.3	16.6
R4C Pc.#392647	Plain	0.65	7.0	36-3/4	73	71	2.08	108.0	97.8	30	34	12.2	12.6
R4C Pc.#392648	Plain	0.65	6.9	36-3/4	73	71	2.08	104.6	98.2	29	32	13.0	13.1

TABLE III (continued)

PHYSICAL TESTS ON FINISHED CLOTH

REPRODUCTION LOTS

Code No.	Thickness (Inches)	Seam Slippage (Lbs.) 1/2" Separation		Permanence of Finish (% Change)				Extractable Matter (%)	pH of Water Extract
		Warp	Fill.	Thickness	Permeability	Shrinkage Warp	Shrinkage Fill.		
R1C	.0049	67.4	79.9	+ 2.1	- 24.5	1.3	0.9	0.494	7.3
R2C	.0049	39.0	71.3	0	- 1.0	1.6	0.6	0.332	7.3
R4C Pc. #392647	.0050	70.5	75.3	0	- 5.8	1.3	0.4	0.46	7.1
R4C Pc. #392648	.0052	74.0	77.2	0	- 6.6	1.4	0.7	0.452	7.1

TABLE IV

AIR PERMEABILITY - $FT.^3/MIN./FT.^2$ - FINISHED CLOTH

Pressure Differential Across Fabric - Inches H_2O: Code No.	1/2"	1"	2"	4"	6"	8"	10"	12"
1-N	33	56	89	138	176	213	243	273
2-N	41	72	111	177	233	282	324	363
3-N	53	81	141	209	258	318	366	408
4-N	104	166	256	361	456	534	609	681
5-N	143	231	332	510	648	762	870	966
6-N	127	200	297	435	555	657	759	855
7-N	35	63	97	163	219	270	312	351
8-N	68	119	194	288	372	452	516	576
9-N	83	140	223	333	430	510	594	669
10-N	130	207	308	475	618	738	846	936
11-N*	173	282	419	642	816	972	1116	1260
12-N*	199	301	450	696	900	1052	1188	1332
1-C	9	15	25	46	65	79	94	113
2-C	22	38	69	118	140	178	207	234
3-C	24	38	70	117	147	177	208	231
4-C	56	85	133	204	261	321	372	414
5-C	67	110	164	272	366	462	531	615
6-C	68	107	166	258	336	411	468	528
7-C	18	32	59	102	133	164	201	216
8-C	48	80	140	211	285	336	393	441
9-C	52	81	142	216	279	336	393	435
10-C	68	110	172	267	354	435	498	561
11-C	95	161	250	378	510	609	705	810
12-C	136	210	321	501	639	774	900	1044

*Area of sample, 1 Sq. inch. All other samples were tested using 2 sq. inch area.

Tests made by Cheney Brothers' Laboratory; U. S. Testing Co. permeability tester.

All Readings on Each Sample Made on One Marked Area Only, and Without Disturbing Sample in Machine Until Series Completed.

TABLE V

AIR PERMEABILITY (FT.^{3}/MIN./FT.^{2}) OF 24 SAMPLES AT VARIOUS PRESSURE DIFFERENTIALS

Pres. Dif. Across Fab. Ins. H_2O: Code No.	1/2"*	1"	2"	4"	6"	8"	10"	12"	15"	18"	20"	"K"***
1N	34.	53.02	84.13	132.2	170.4	200.9	235.8	267.	306.1	344.8	370.	.645
2N	52.	75.5	123.6	196.	263.	296.3	346.2	386.75	442.	487.	520.2	.619
3N	57.	86.62	135.8	207.	267.	317.2	364.	408.	467.2	522.4	556.8	.619
4N	97.	152.1	221.4	335.2	424.6	502.6	575.	629.8	716.	793.8	847.	.576
5N	138.	194.8	302.4	455.2	575.3	679.5	774.8	863.8	982.8	1089.	1151.7	.582
6N	118.	170.4	267.	402.4	509.4	606.6	695.4	774.8	880.6	982.8	1050.	.602
7N	38.	57.9	96.16	155.6	200.9	245.4	283.	319.05	370.	413.6	444.1	.662
8N	77.	114.6	180.4	275.	354.4	422.	480.6	534.2	612.4	679.5	726.	.614
9N	91.	138.6	221.	340.7	446.25	531.	612.4	684.8	781.85	872.2	931.	.634
10N	120.	179.55	279.	432.4	545.4	651.4	747.4	828.4	946.	1057.35	1129.95	.610
11N	154.	233.6	364.	569.	731.2	868.9	994.3	1111.8	1277.3	1433.5	1523.1	.625
12N	172.	259.	408.	609.	796.	939.1	1075.5	1191.5	1371.5	1532.	1631.4	.611
1C	9.	16.53	24.3	43.14	59.12	75.11	89.11	101.92	121.4	139.5	151.1	.759
2C	26.5	40.3	68.08	110.9	145.	175.	202.6	228.9	259.	291.	309.8	.656
3C	31.5	47.09	77.84	125.6	161.25	194.8	223.8	252.6	291.	324.6	348.	.647
4C	55.	82.27	127.2	198.2	250.2	298.7	344.8	385.	442.8	498.2	531.2	.621
5C	60.	87.69	141.8	229.8	296.3	357.35	408.	459.	531.	595.	641.4	.659
6C	60.	92.46	145.	229.8	296.3	357.35	408.	459.	527.4	591.25	635.6	.642
7C	24.	37.67	65.02	110.9	153.15	176.5	211.8	247.8	277.	313.5	338.8	.710
8C	62.	92.46	154.8	249.	318.5	386.75	446.25	502.2	575.8	647.2	690.1	.648
9C	60.	87.69	143.4	228.9	296.3	351.8	408.	459.	527.4	588.6	632.7	.640
10C	62.	94.52	152.	246.	312.95	382.5	442.	495.	572.6	647.2	690.1	.661
11C	95.	147.8	238.	374.	484.	585.2	674.2	763.05	880.6	990.2	1057.5	.654
12C	109.	182.6	244.2**	337.6**	556.	672.6	771.7	860.8	980.6	1099.7	1179.8	.622

*Values shown are extrapolations of logarithmic curves. 1/2" Readings not taken at WADC.
**Accuracy of test results doubtful.
***See Section II
Air Permeability Readings Made on WADC Frazier 20" H_2O Machine
(Single readings in same marked areas as for Table IV)

TABLE VI

AIR PERMEABILITY ($FT.^3/MIN./FT.^2$) OF 24 PRODUCTION SAMPLES

Pres. Dif. Across Fab. Ins. H_2O / Code No.	1"	2"	4"	6"	8"	10"	12"	15"	18"	20"	"K"*
1N	57.3	91.1	143.9	178.3	214.4	245.3	273.8	316.8	354.9	379.2	.624
2N	80.9	132.2	200.6	258.7	308.6	352.4	393.1	448.2	498.8	531.2	.605
3N	86.6	137.2	207.2	265.9	317.2	363.9	406.3	465.3	518.9	553.2	.615
4N	157.6	238.2	357.2	446.7	529.0	601.1	669.3	759.9	844.5	898.2	.579
5N	219.5	335.8	505.1	632.3	744.8	843.9	936.7	1058.1	1178.4	1252.9	.575
6N	199.5	300.9	455.8	570.8	668.8	768.4	854.3	970.8	1077.9	1147.7	.582
7N	61.4	102.9	163.7	215.5	260.2	301.9	341.1	393.6	444.4	474.9	.665
8N	128.2	211.3	312.9	399.2	475.5	543.5	606.8	691.8	769.8	815.5	.609
9N	158.2	244.8	378.3	483.0	567.7	651.4	724.8	828.4	919.8	1032.4	.613
10N	192.9	299.3	458.9	572.9	685.3	783.2	889.7	999.1	1117.5	1189.3	.605
11N	290.4	432.2	657.6	836.9	988.8	1132.1	1254.9	1432.6	1595.8	1700.8	.591
12N	294.1	452.5	682.7	861.9	1021.2	1161.4	1292.5	1475.8	1640.4	1743.9	.591
1C	16.4	29.6	51.6	69.5	85.8	100.7	114.9	134.1	153.0	164.6	.740
2C	43.6	74.3	122.8	159.2	189.3	219.2	246.3	290.1	313.5	333.9	.663
3C	42.7	71.1	115.6	150.8	178.3	207.4	231.5	266.8	297.8	318.7	.645
4C	82.0	127.6	196.9	249.9	298.3	343.8	386.0	440.0	499.4	533.7	.622
5C	117.1	187.2	289.3	377.9	456.2	526.8	598.3	695.1	788.5	849.8	.658
6C	106.5	167.2	264.2	332.8	402.9	455.6	525.9	607.5	685.1	740.1	.643
7C	40.3	69.4	115.4	151.9	180.8	210.5	238.7	277.0	312.7	336.0	.679
8C	88.8	145.1	226.1	283.0	335.1	385.9	427.6	487.1	543.6	577.6	.597
9C	91.8	145.9	229.0	291.9	347.4	398.4	445.2	509.4	566.8	607.7	.626
10C	105.7	172.4	274.0	347.9	423.9	490.7	553.9	640.3	723.6	778.4	.660
11C	160.6	259.7	407.4	539.9	640.8	740.9	834.9	961.2	1083.9	1170.4	.658
12C	213.2	331.9	510.9	643.0	771.7	886.4	993.8	1142.9	1285.4	1372.6	.618

Note: As reported, WADC letter to Cheney Brothers, May 11, 1954. (Average of 5 readings each.)
*See Section II.

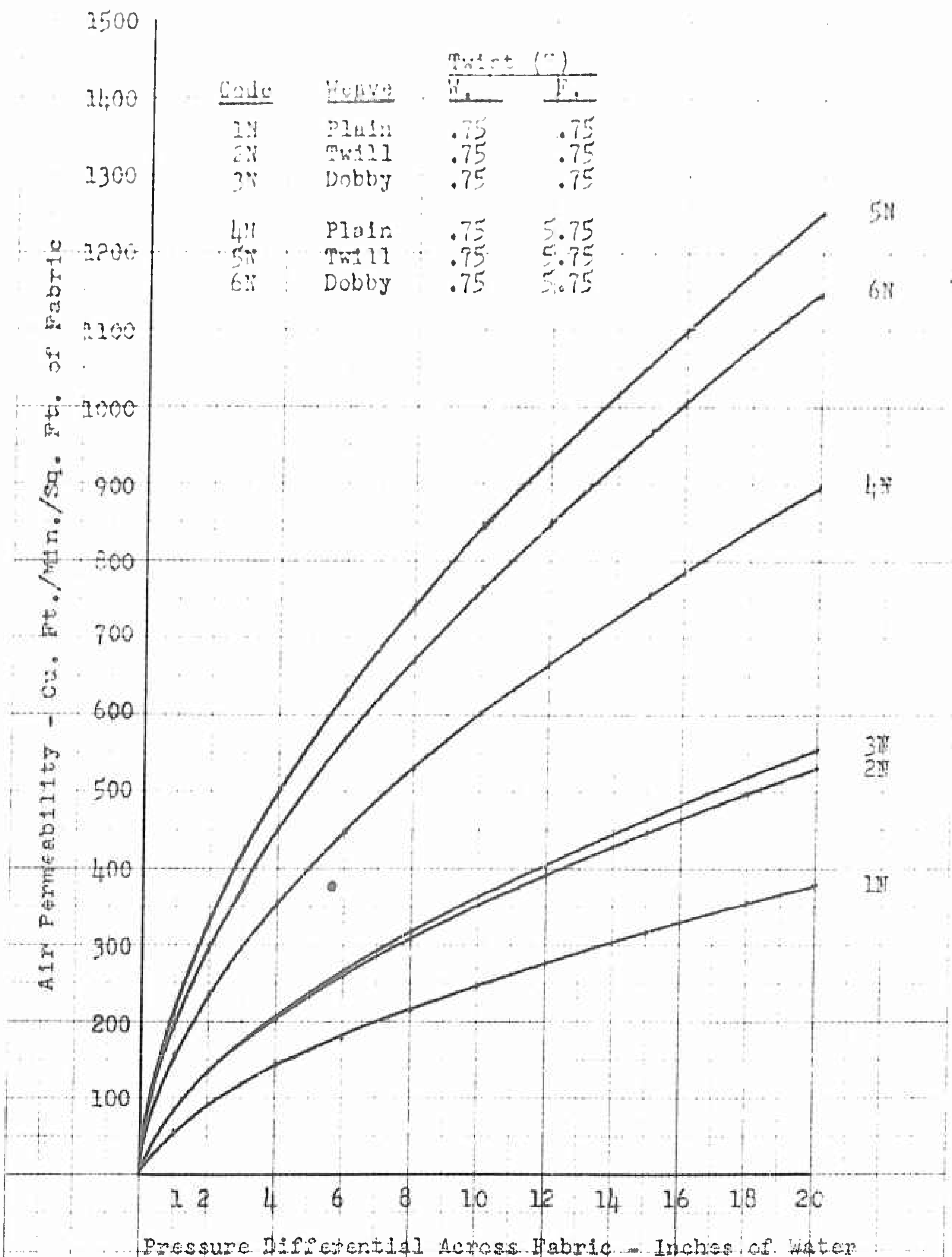
Air Permeability Readings Made on WADC Frazier 20" H_2O Machine.
(Average of 5 Readings Each)

GRAPH 2

AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1N-6N

DATA FROM TABLE VI

(See also GRAPH 7)

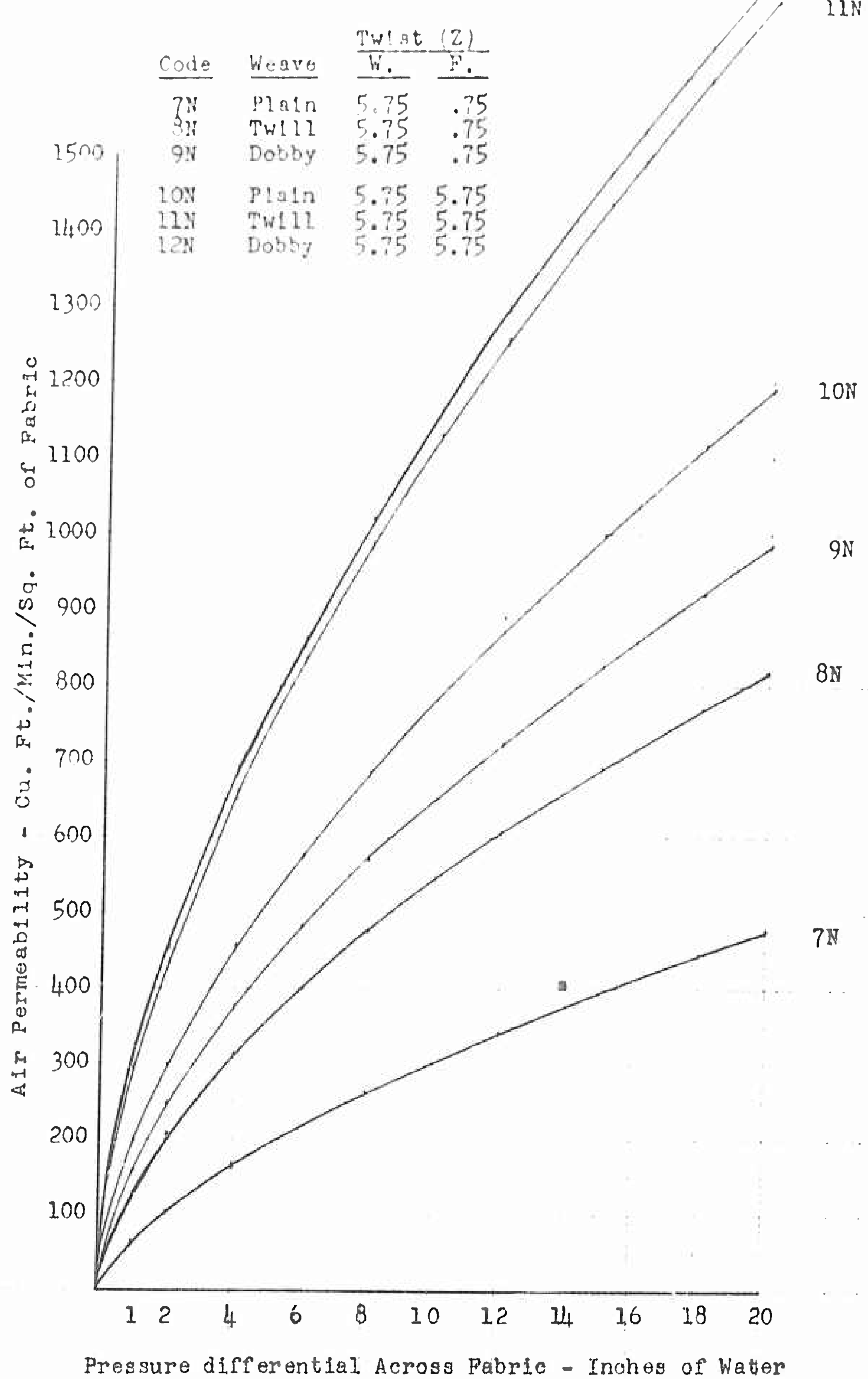


GRAPH 3

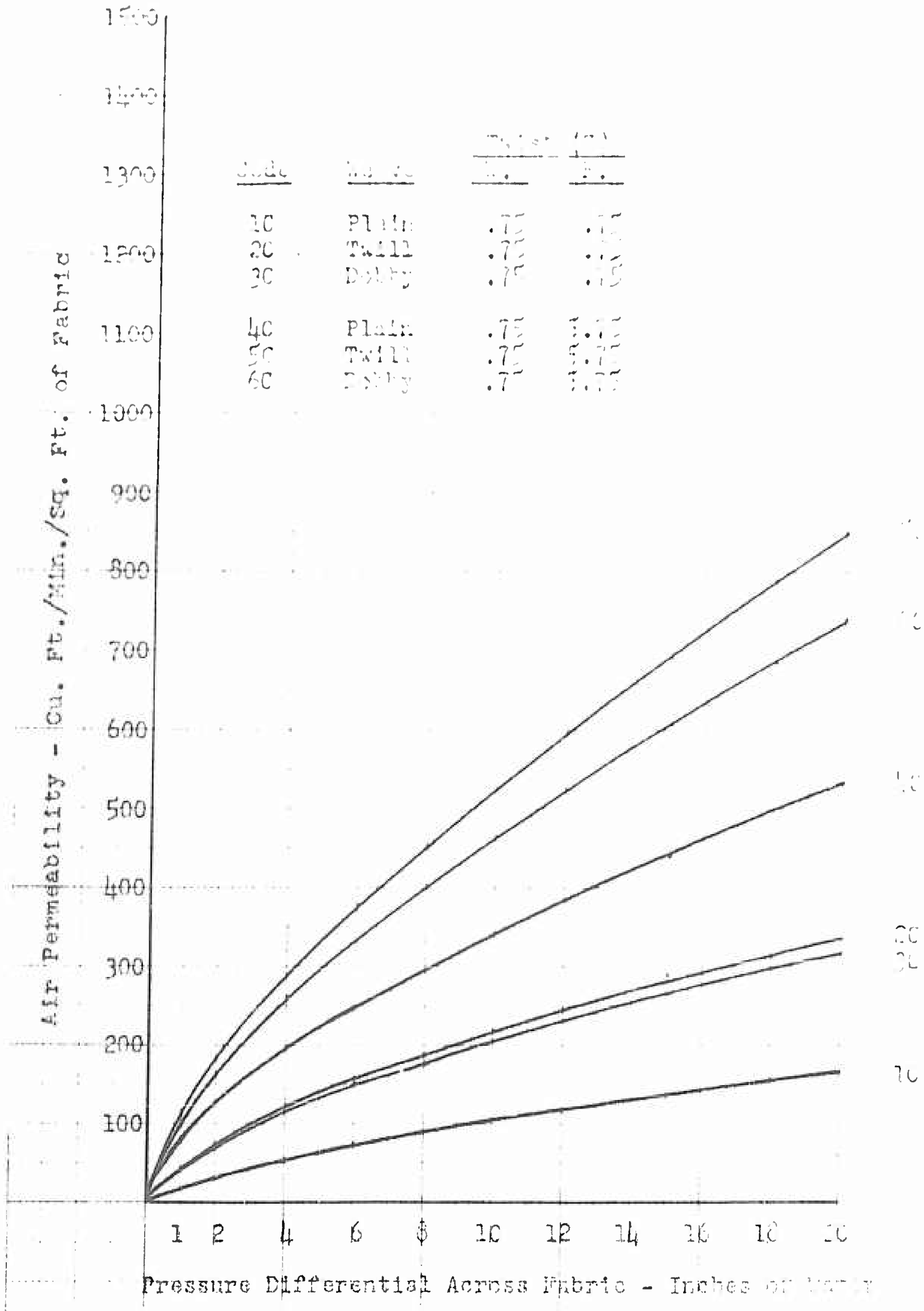
AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7N-12N

DATA FROM TABLE VI

(See also GRAPH [illegible])



GRAPH 4
AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1C-6C
DATA FROM TABLE VI
(See also GRAPH 9)



GRAPH 5
AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7C-12C
DATA FROM TABLE VI
(See also GRAPH 10)

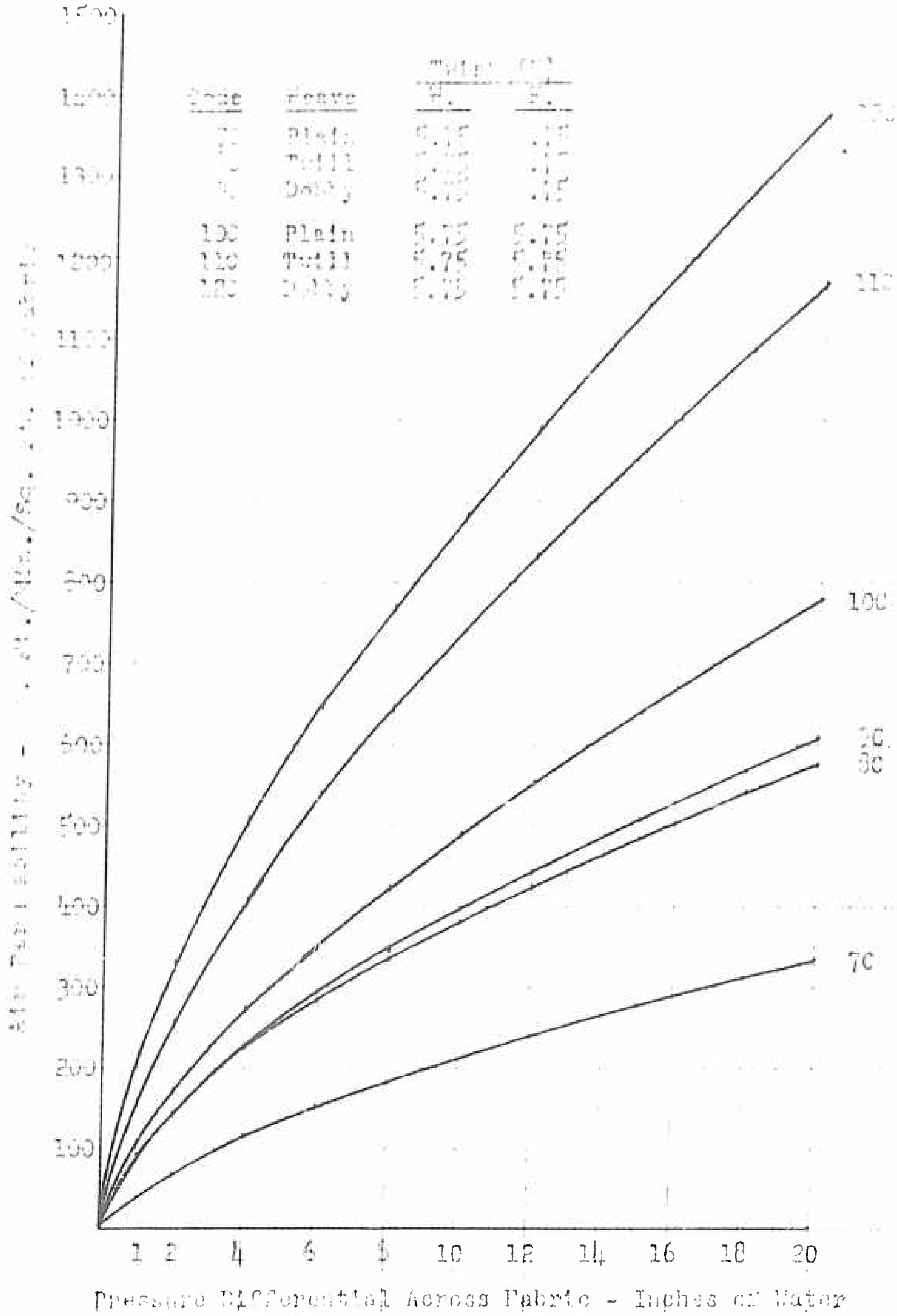


TABLE VII

AIR PERMEABILITY - $FT.^3/MIN./FT.^2$ - FINISHED CLOTH

REPRODUCTION LOTS

Pressure Differential Across Fabric - Inches H_2O: Code No.	1/2"	1"	2"	4"	6"	8"	10"	12"
R1C	9.27	15.9	32.1	55.8	71.4	90.6	108.0	123.0
R2C	29.4	49.7	80.7	140.1	174.0	207.0	239.0	275.0
R4C - Pc.#392647	49.2	75.0	126.0	189.0	243.0	293.0	324.0	369.0
R4C - Pc.#392648	50.1	76.2	126.1	193.5	243.0	297.0	336.0	396.0

Cheney Brothers' Laboratory, U. S. Testing Co. permeability tester, 2 sq.in. sample area.

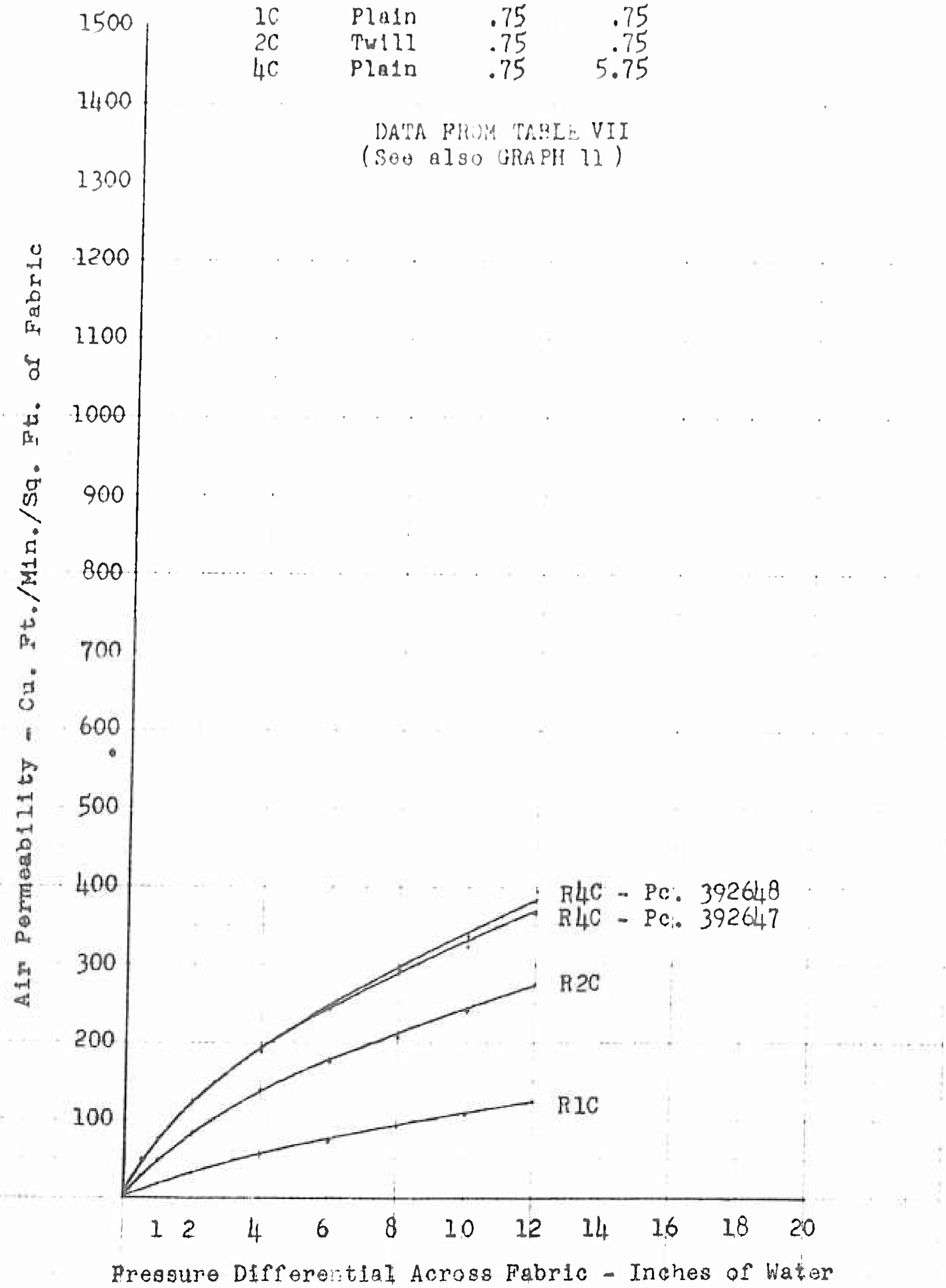
All Readings on Each Sample Made on One Marked Area Only, and Without Disturbing Sample in Machine Until Series Completed.

GRAPH 6

AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL,
1/2" - 12", TESTS - REPRODUCTION LOTS R1C, R2C and R4C

Code	Weave	Twist (Z) W.	Twist (Z) F.
1C	Plain	.75	.75
2C	Twill	.75	.75
4C	Plain	.75	5.75

DATA FROM TABLE VII
(See also GRAPH 11)



SECTION II

DISCUSSION

A. MATHEMATICAL RELATIONSHIPS

1. A mathematical analysis of air permeability data from TABLE VI, tests made by the Wright Air Development Center Materials Laboratory on fabrics woven under this contract, discloses that the relationship, air permeability vs. pressure differential, is an exponential function that should result in a straight line when plotted on full logarithmic paper. (See also GRAPHS 7 through 11.) Additional data from tests made on over a hundred fabric samples and reported under other contracts (2, 3, 4, 5)* have been plotted and the results consistently bear out the above observation.

It also appears that the slope of the straight line plotted on logarithmic paper is an indication of the extent to which a fabric conforms to the concept of "Constant Effective Porosity" (1)*. (See APPENDIX I for mathematical development.)

It has been found empirically that the relationship between air permeability and pressure differential is adequately described by the following equation:

$$\log Mn/Mx = K \log h_n/h_x$$

where Mn and Mx are air permeabilities at pressure differentials of h_n and h_x, and K is a constant for any particular sample of fabric, but not the same value for all fabrics.

The test of the above relationship has been made in most cases by fitting a straight line to the data plotted on logarithmic paper and testing the fit by eye. For most of the data available, K has been determined by one or more of the methods described in APPENDIX II.

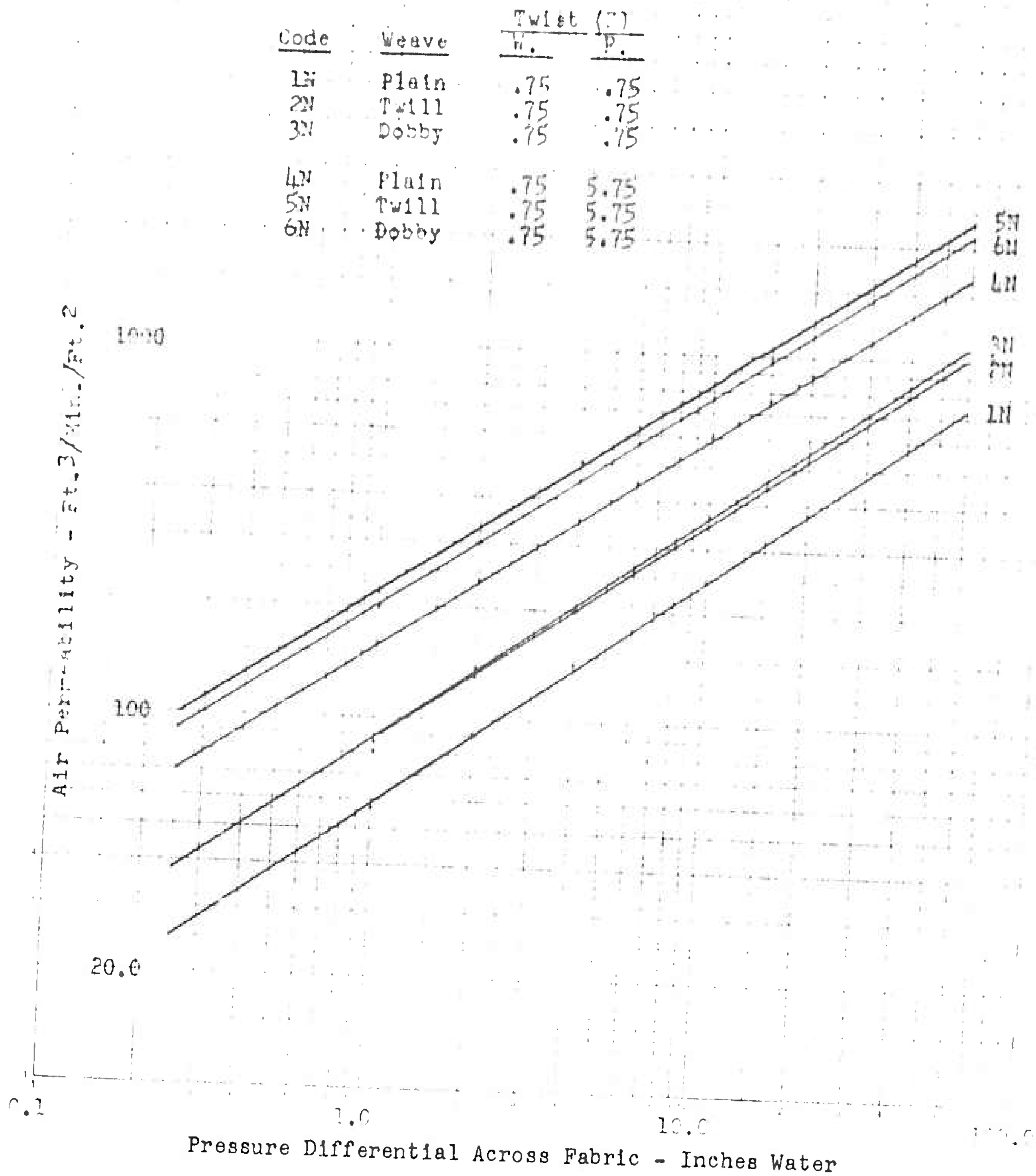
*APPENDIX III

GRAPH 7

(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1N-6N

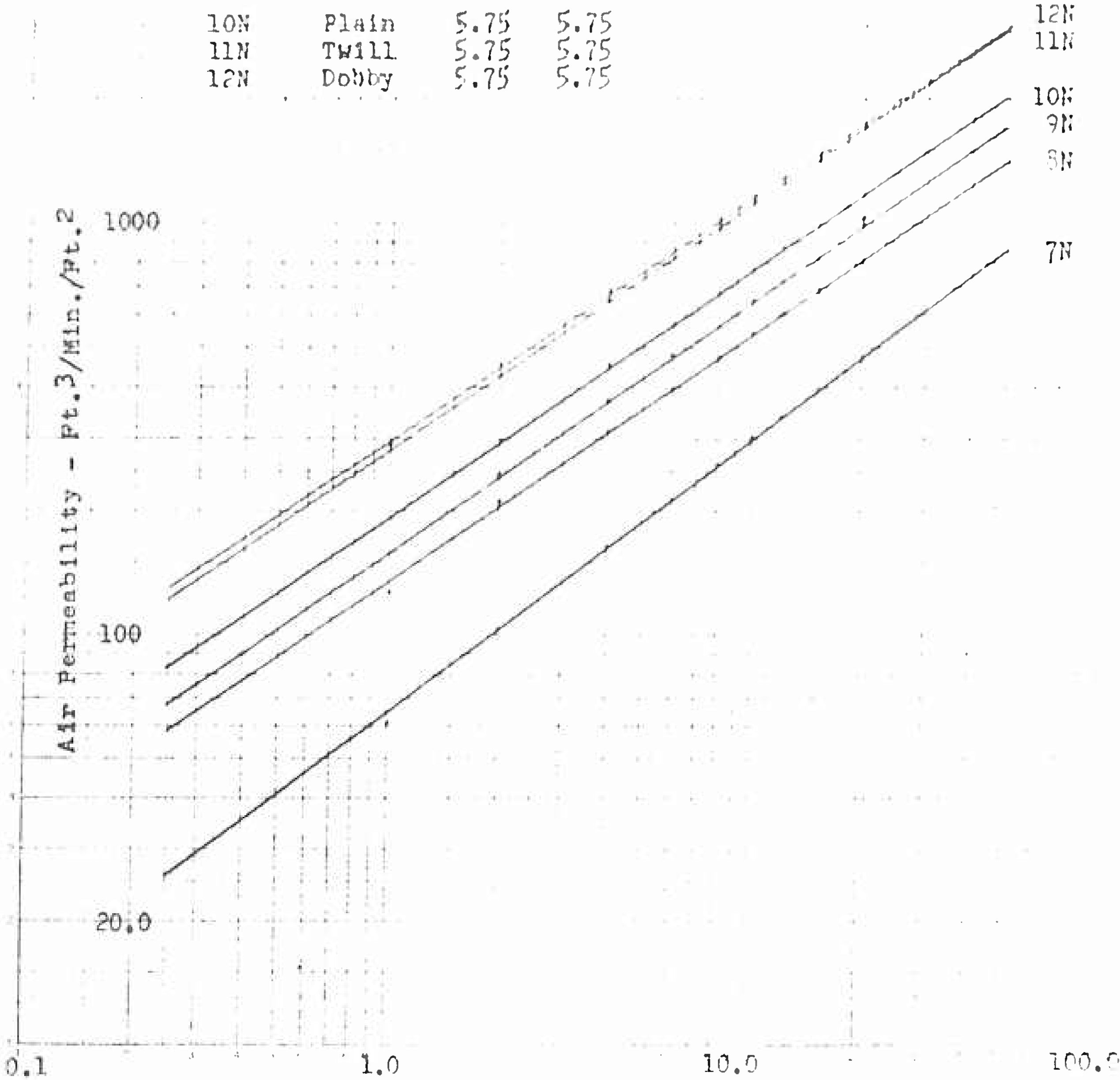
DATA FROM TABLE VI

(See also GRAPH 2)



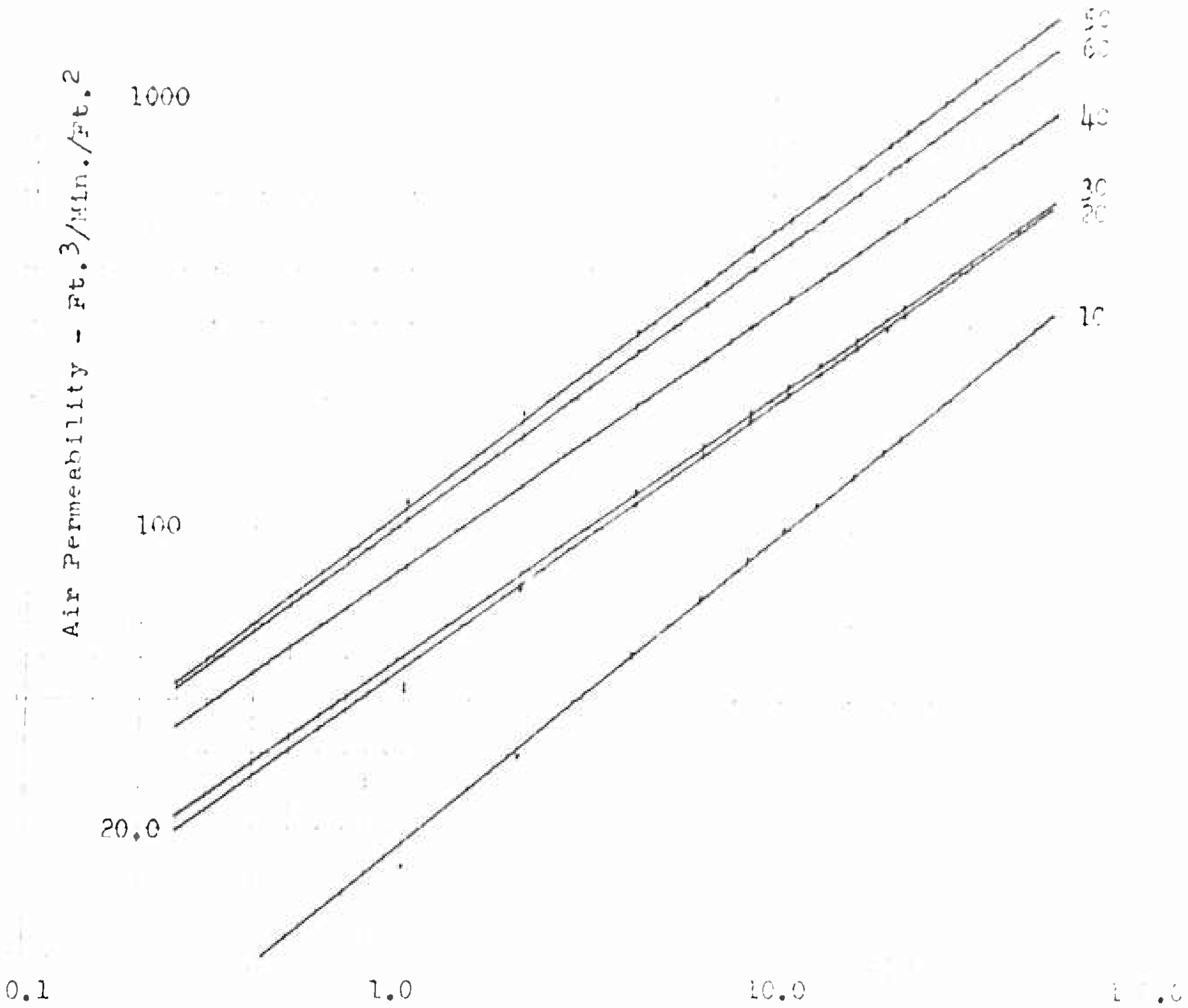
GRAPH 8
(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7N-12N
DATA FROM TABLE VI
(See also GRAPH 3)

Code	Weave	Twist (Z) W.	Twist (Z) F.
7N	Plain	5.75	.75
8N	Twill	5.75	.75
9N	Dobby	5.75	.75
10N	Plain	5.75	5.75
11N	Twill	5.75	5.75
12N	Dobby	5.75	5.75



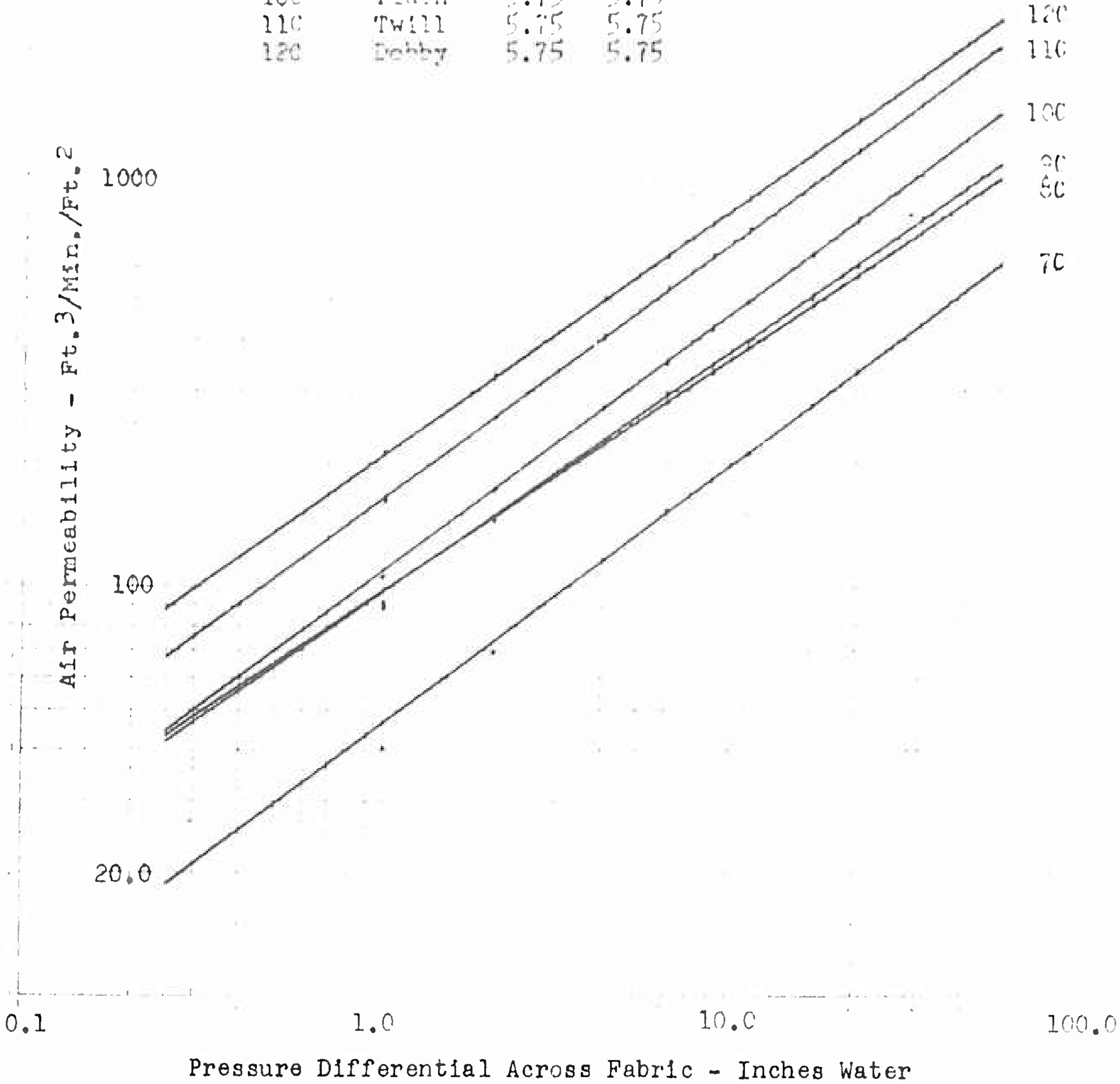
GRAPH 9
(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1C-6C
DATA FROM TABLE VI
(See also GRAPH 4)

Code	Weave	Twist ([illegible]) W.	Twist ([illegible]) F.
1C	Plain	.75	.75
2C	Twill	.75	.75
3C	Dobby	.75	.75
4C	Plain	.75	5.75
5C	Twill	.75	5.75
6C	Dobby	.75	5.75



GRAPH 10
(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7C-12C
DATA FROM TABLE VI
(See also GRAPH 5)

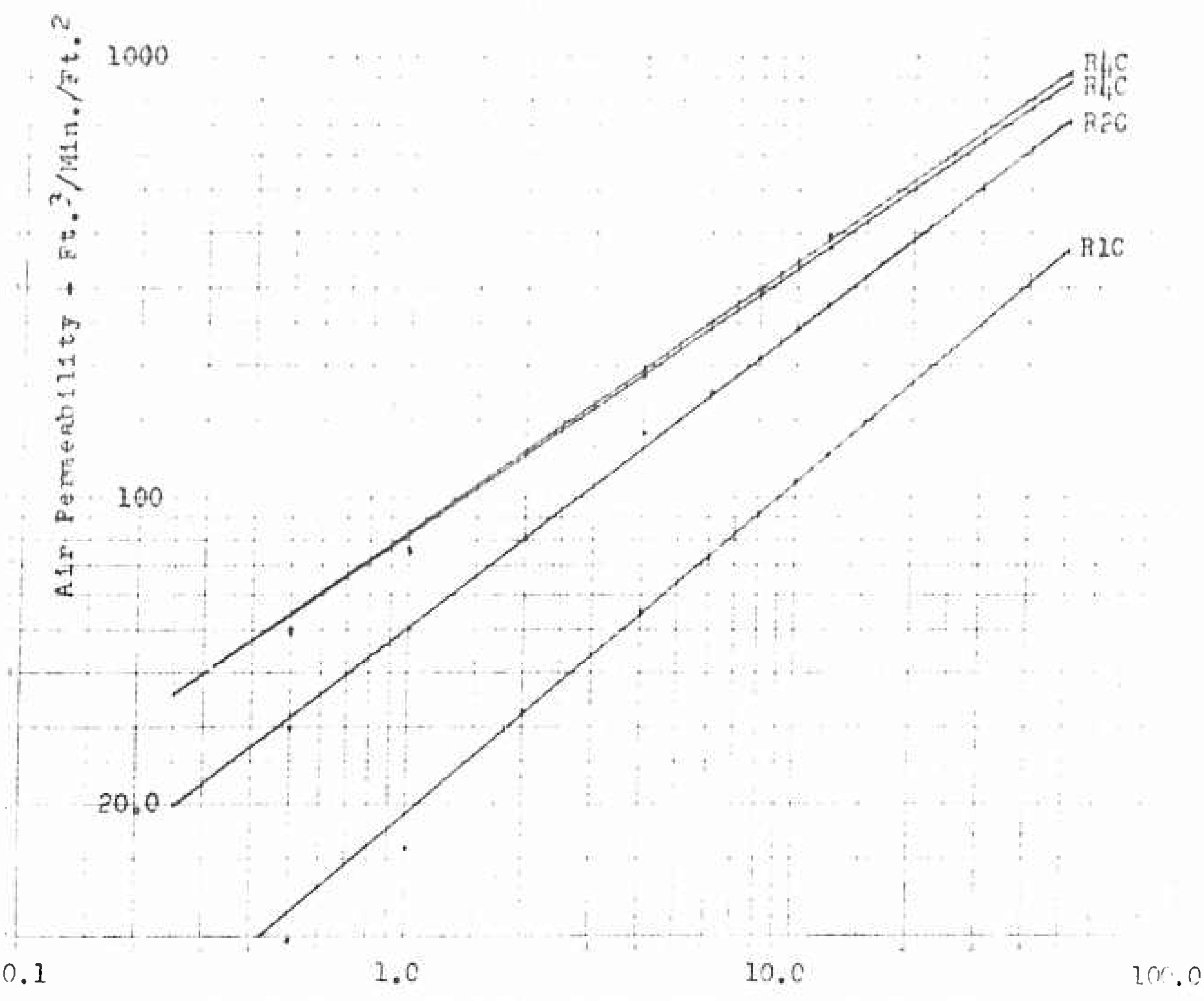
Code	Weave	Twist (Z) W.	Twist (Z) F.
7C	Plain	5.75	.75
8C	Twill	5.75	.75
9C	Dobby	5.75	.75
10C	Plain	5.75	5.75
11C	Twill	5.75	5.75
12C	Dobby	5.75	5.75



GRAPH 11
(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL,
1/2" - 12", TESTS - REPRODUCTION LOTS R1C, R2C and R4C

DATA FROM TABLE VII
(See also GRAPH 6)

Code	Weave	Twist (%) W.	Twist (%) F.
R1C	Plain	.75	.75
R2C	Twill	.75	.75
R4C	Plain	.75	5.75



2. Significance of "K"

The value of "K" represents the slope of the straight line plotted on logarithmic graph paper and therefore defines the relationship between air permeability and pressure differential for the fabric represented. Fabrics having relatively higher permeability at higher pressures will show higher values of "K". The fabrics covered by our study have shown values of "K" ranging from 0.518 to 0.75. Published data for various tests on air flow through holes in metal plates and well-rounded metal orifices also show linear relationship with "K" values between 0.495 (5.0-inch diameter hole in metal plate .057 inch thick (6)*), and 0.539 for well-rounded 1 mm orifice. (Frazier's calibration for high pressure differential permeability tester.)

Some of the variables controlling "K" are indicated by this study, while others remain to be discovered.

One important variable controlling "K" appears to be the "distortability" of the fabric under increasing pressure differentials. Any variation in construction or finishing technique which makes it possible for a fabric to distort more readily tends to increase the value of "K". Some of these variations and the level of significance for the data obtained are shown in TABLE VIII. As can be seen in this table, data obtained under this contract and from study of the literature were sufficient to establish only filling twist and grey calendering as of definite significance. In all the other cases it was possible to study, the amount of data available were only great enough to establish trends.

*APPENDIX III

TABLE VIII

FACTORS AFFECTING VALUE OF "K"

Source of Data	Fabric	Factors Affecting "K"			"K"	Level of Significance
Data from TABLE VI	2.25-oz. Nylon	Grey Calendered (1C-12C)			.651)	.001
		Uncalendered (1N-12N)			.604)	
		Weave of Calendered Goods				
		Plain			.675)	.10 - .50
		Twill			.644)	
		Dobby			.633)	
		Weave of Uncalendered Goods				
		Plain			.618)	.50
		Twill			.595)	
		Dobby			.600)	
		Filling Twist of Calendered Goods				
		3/4			.658)	.50
		5-3/4			.643)	
		Filling Twist of Uncalendered Goods				
		3/4			.622)	.005
		5-3/4			.587)	
		Warp Twist of Calendered Goods				
		3/4			.662)	.25
		5-3/4			.640)	
		Warp Twist of Uncalendered Goods				
		3/4			.597)	.25
		5-3/4			.612)	
(2)*	1.1 - 1.8-oz Nylon	Construction -	Ends	Picks		
			70	40	.536	
			70	50	.535	
			70	60	.542	
			70	70	.577	
			70	80	.582	
			70	90	.590	
			125	40	.558	
			125	50	.569	
			125	60	.584	
			125	70	.601	
			125	80	.626	

*APPENDIX III

TABLE VIII continued

FACTORS AFFECTING VALUE OF "K"

Source of Data	Fabric	Factors Affecting "K"	"K"	Level of Significance
Cheney Brothers' Tests - for Georgia Tech. R & D. Contract dated 2/22/54	1.1-oz. Nylon Ripstop	Grey	.560	
		Finished - Uncalendered	.620	
		" - Grey Calendered 19 Tons	.680	
		" - " " 25 "	.690	
		" - " " 50 "	.680	
		" - " " 100 "	.660	
		" - " " 19 " ,Heat Treated	.660	
(4)*	1.1-oz. Nylon Ripstop (6 samples)	Calendered (Avg. 3)	.608	
		Uncalendered (Avg. 3)	.562	
		Filling Twist		
		1/2 (Avg. 2)	.618	
		7 (Avg. 2)	.585	
		30 (Avg. 2)	.552	
(4)*	1.6-oz. Nylon Twill (16 samples)	Calendered (Avg. 8)	.608	
		Uncalendered (Avg. 8)	.550	
		Filling Twist		
		1/2 (Avg. 4)	.654	
		5 (Avg. 4)	.590	
		15 (Avg. 4)	.538	
		35 (Avg. 4)	.536	
		Warp Twist		
		7 (Avg. 8)	.581	
		10 (Avg. 8)	.578	

*APPENDIX III

3. Practical Use of "K" in Fabric Design

The controllable fabric construction factors which seem to affect "K" are:

Fabric Geometry

- Fiber
- Yarn size and filament count
- Weave
- Twist
- End and pick count

Processing Variables

- Grey calendering
- Various dyeing and finishing variables

Data obtained under this contract indicate three of these factors as of the greatest significance.

(1) When a grey fabric is calendered, the resultant permeabilities at both low and high pressure differentials are significantly reduced from those obtained on the same fabric finished without calendering. This is, of course, a well-known standard practice in the industry. However, the value of "K" is increased by this technique so that the permeability values for the higher pressures are not decreased in direct proportion to the decrease at 1/2-inch pressure.

(2) A second factor which shows considerable significance is a change of filling twist. As filling twist is increased, the "K" value decreases, probably because it makes a rounder, firmer yarn, less subject to distortion.

(3) A third factor which is important because it does not change the value of "K" significantly, but does change permeability, is a change in the amount of weight applied in calendering, once the fact of calendering is established. This is a valuable tool if the fabric is designed for a calendered finish, as it permits much closer control of permeability than would be practical if it were necessary to shift back and forth from a non-calendered to a calendered condition.

The other variables listed undoubtedly control "K" to some extent, but so far only enough data are available to indicate a trend; namely, that any factor that makes it easier for a yarn or fabric to distort under an applied pressure differential tends to increase the value of "K".

Example 1 - A fabric is desired which has a permeability at 1/2-inch pressure of 50 to 90 cu ft/min/sq ft and a permeability at 20 inches pressure of 500 to 700 cu ft/min/sq ft. Another fabric already in existence meets all the physical and chemical requirements, except that it has a 1/2-inch pressure permeability of 157 and a 20-inch pressure permeability of 1226. The "K" value is 0.557. The existing fabric has a filling twist of 5 turns "Z" and was not calendered in finishing.

By reference to TABLE IX or GRAPH 12, it will be seen that for a permeability range of 50 to 90 at 1/2-inch pressure differential, "K" values in the range 0.500 to 0.700 produce the required 20-inch value, although at the extremes of this range the low pressure tolerance would be too small to be practical. The best "K" value would be approximately 0.575, which would allow a 1/2-inch pressure permeability range of 60 to 85, or 72.5 plus or minus 17%. This tolerance, while narrow, could probably be met.

In order to produce the desired properties, the filling twist was decreased to 3.5 turns per inch and finishing planned to involve a calendering in the grey. Both of these changes increase "K", while decreasing the 1/2-inch permeability and the result is a fabric meeting the new specification.

Example 2 - Given the information included in TABLE V on the air permeabilities and values of "K" of the 24 samples woven under this contract, design one or more fabrics which will have an air permeability of 80 at 1/2-inch pressure differential and a 20-inch air permeability of 800.

The procedure followed here is to compare two samples which vary only in filling twist, and calculate the twist required to produce a 1/2-inch air permeability ($M_{\frac{1}{2}}$) of 80. For each such possible set, calculate the value of "K" for the resulting modification and the 20-inch differential permeability (M_{20}). Select the one or more results which are the closest solution to the problem.

Weave	Code No.	Twist Warp	Twist Fill.	$M_{\frac{1}{2}}$	"K"	Calculated Modification for $M_{\frac{1}{2}} = 80$: Fill. Twist	"K"	M_{20}
Plain	(1N (4N	3/4 3/4	3/4 5-3/4	34 97	.645) .576)	4.4	.595	719
Twill	(2N (5N	3/4 3/4	3/4 5-3/4	52 138	.639) .591)	2.37	.623	796
Dobby	(3N (6N	3/4 3/4	3/4 5-3/4	57 118	.619) .602)	2.63	.613	768
Plain	(7N (10N	5-3/4 5-3/4	3/4 5-3/4	38 120	.675) .610)	3.31	.642	855
Twill	(8N (11N	5-3/4 5-3/4	3/4 5-3/4	77 154	.614) .625)	.95	.614	771
Twill	(8C (11C	5-3/4 5-3/4	3/4 5-3/4	62 95	.665) .654)	3.48	.659	911
Dobby	(9C (12C	5-3/4 5-3/4	3/4 5-3/4	60 109	.654) .622)	2.79	.641	852

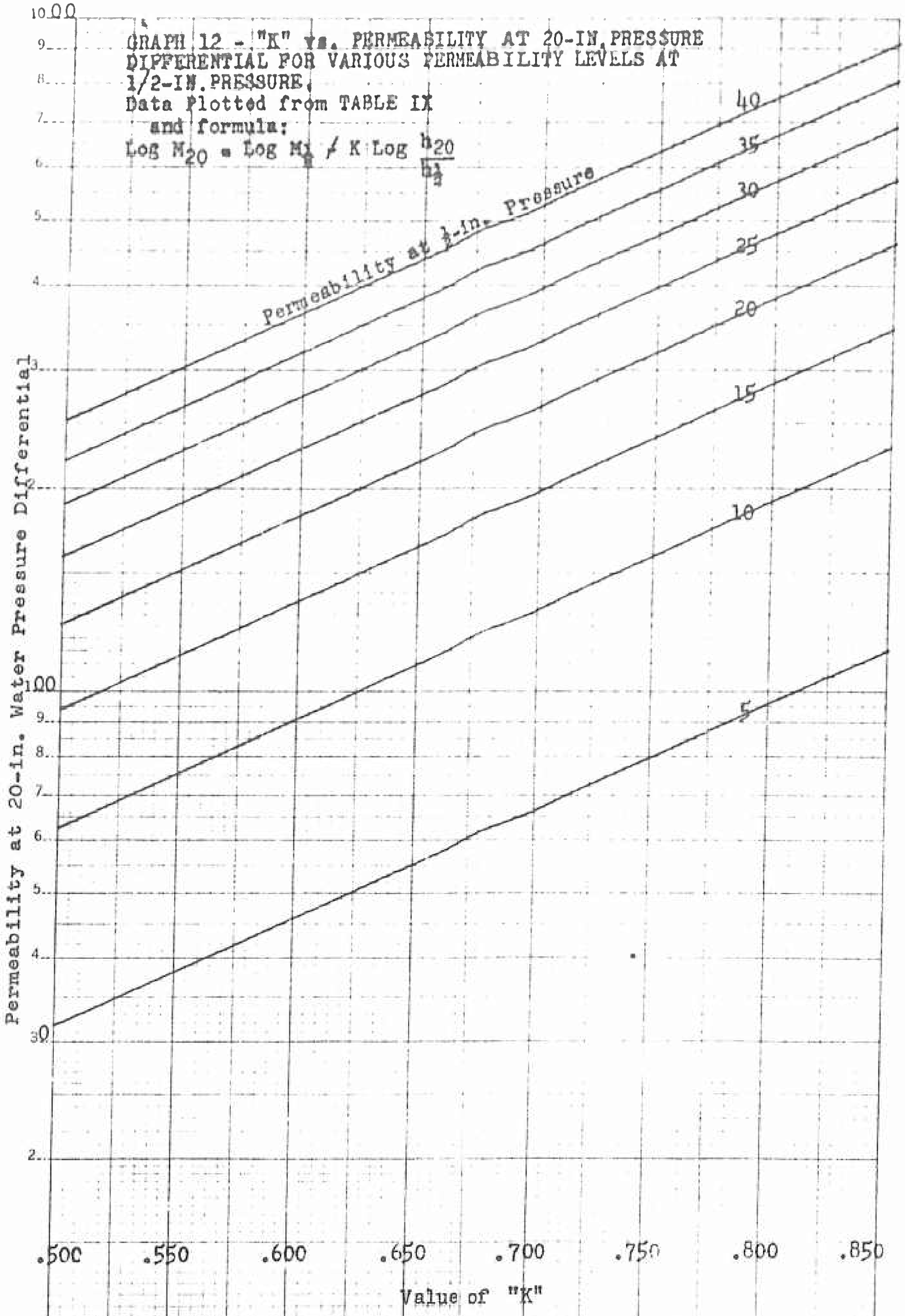
It can be seen that the modified fabric most closely fitting the specifications is the second one, Twill Weave, 3/4 twist in the warp, 2.37 twist in the filling, "K" = .623, 20-inch air permeability - 796. The other figures give an idea of the range of "K" and M_{20} which should be obtainable by modifying weave, warp twist, filling twist, and grey calendering. Another fact which can be seen here is the necessity of changing two variables simultaneously if "K" is to be changed while keeping $M_{\frac{1}{2}}$ constant.

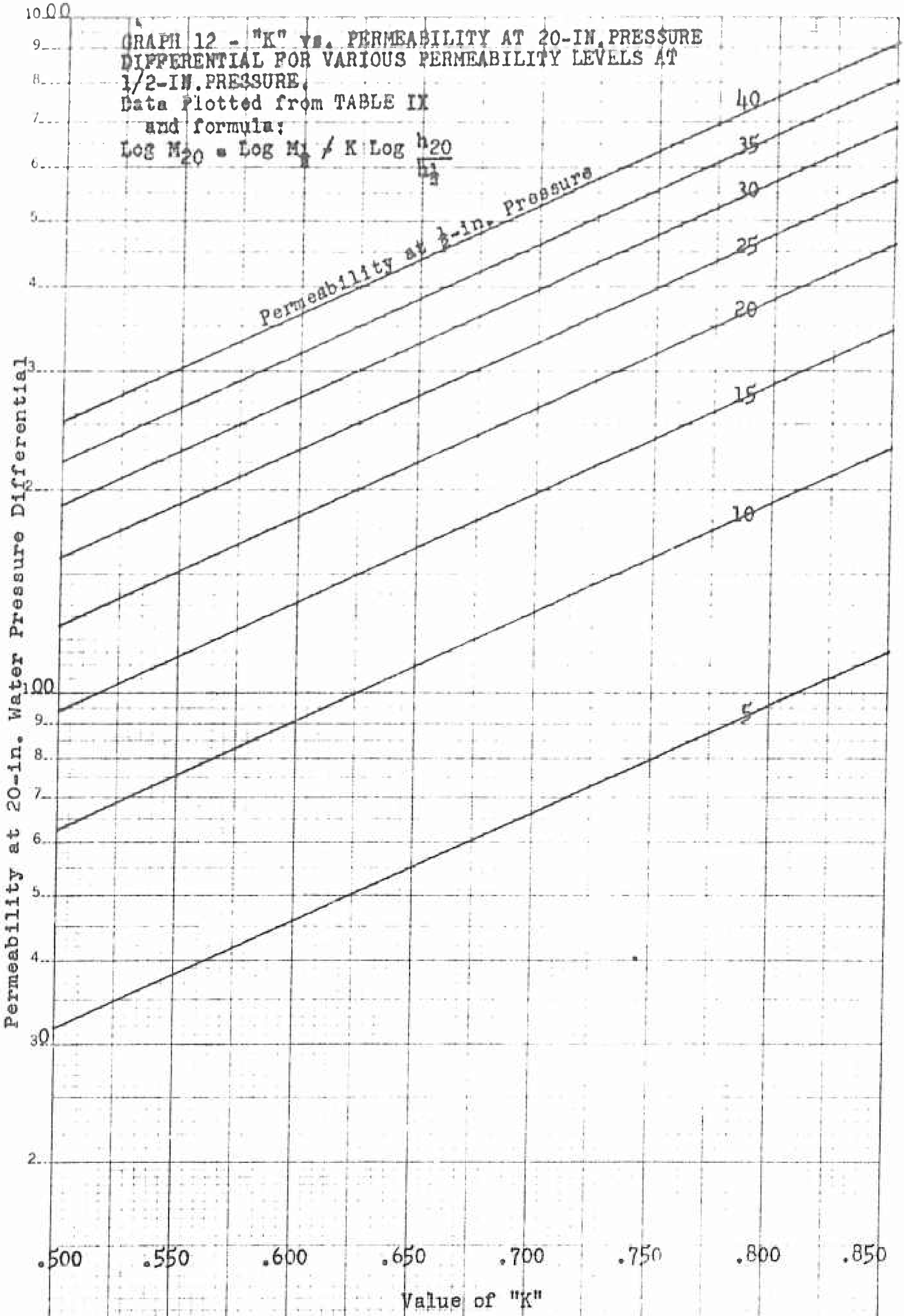
TABLE IX

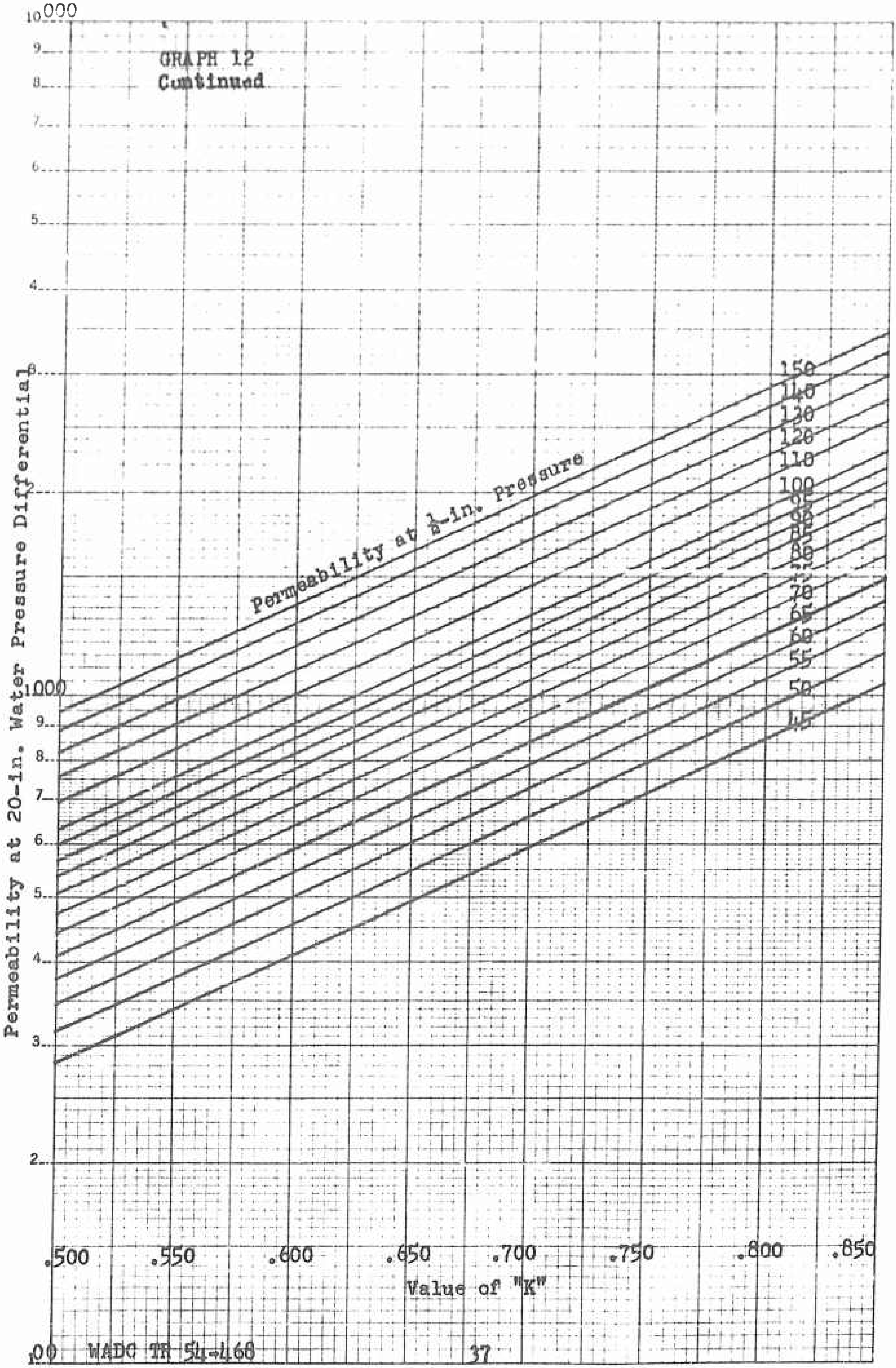
Calculated Values of Air Permeability (Cu Ft/Min/Sq Ft) at 20-In. Water Pressure Differential for Different Values of "K"

Permeability at 1/2-in. Pressure	"K" .500	"K" .525	"K" .550	"K" .575	"K" .600	"K" .625	"K" .650	"K" .675	"K" .700	"K" .725	"K" .750	"K" .775	"K" .800	"K" .825	"K" .850
100	632	694	761	834	915	1003	1100	1206	1323	1450	1590	1744	1913	2097	2300
95	600	659	722	792	869	953	1045	1145	1256	1377	1510	1657	1817	1992	2185
90	569	624	684	751	823	903	990	1085	1190	1305	1431	1570	1724	1888	2070
85	538	590	646	709	777	853	935	1025	1124	1233	1352	1482	1625	1783	1955
80	506	555	608	667	732	802	880	965	1058	1160	1272	1395	1530	1678	1840
75	474	520	570	626	686	752	825	905	992	1088	1193	1308	1434	1573	1725
70	443	485	532	584	640	702	770	844	926	1015	1113	1221	1339	1468	1610
65	409	448	491	539	591	652	710	779	854	937	1027	1134	1243	1363	1495
60	379	416	456	500	549	602	660	724	794	870	954	1047	1148	1258	1380
55	348	381	418	459	503	552	605	663	727	798	875	959	1052	1153	1265
50	316	347	380	417	457	501	550	603	661	725	795	872	956	1049	1150
45	284	312	342	375	411	451	495	542	595	652	715	785	860	944	1035
40	253	277	304	334	366	401	440	482	529	580	636	698	765	839	920
35	221	242	266	292	320	351	389	422	463	507	556	610	669	734	805
30	190	208	228	250	274	301	330	362	397	435	477	523	574	629	690
25	158	173	190	208	228	251	275	301	331	362	397	436	478	524	575
20	126	139	152	167	183	201	220	241	265	290	318	349	383	419	460
15	94	104	114	125	137	151	165	181	198	217	238	261	287	314	345
10	63	69	76	83	92	100	110	121	132	145	159	174	191	210	230
5	32	35	38	42	46	50	55	60	66	72	80	87	96	105	115

Formula: $\text{Log } M_{20} = \log M_{\frac{1}{2}} + K \log \frac{h = 20}{h = \frac{1}{2}}$


GRAPH 12 - "K" vs. PERMEABILITY AT 20-IN. PRESSURE DIFFERENTIAL FOR VARIOUS PERMEABILITY LEVELS AT 1/2-IN. PRESSURE.
Data Plotted from TABLE IX and formula:
$\text{Log } M_{20} = \text{Log } M_{\frac{1}{2}} + K \text{ Log } \frac{h_{20}}{h_{\frac{1}{2}}}$
Permeability at ½-in. Pressure
40
35
30
25
20
15
10
5
Permeability at 20-in. Water Pressure Differential
1000
100
30
.500
.550
.600
.650
.700
.750
.800
.850
Value of "K"


GRAPH 12 - "K" vs. PERMEABILITY AT 20-IN. PRESSURE DIFFERENTIAL FOR VARIOUS PERMEABILITY LEVELS AT 1/2-IN. PRESSURE.
Data Plotted from TABLE IX and formula:
$\text{Log } M_{20} = \text{Log } M_{\frac{1}{2}} + K \text{ Log } \frac{h_{20}}{h_{\frac{1}{2}}}$
Permeability at ½-in. Pressure
40
35
30
25
20
15
10
5
Permeability at 20-in. Water Pressure Differential
1000
100
30
.500
.550
.600
.650
.700
.750
.800
.850
Value of "K"


GRAPH 12
Continued
Permeability at 20-in. Water Pressure Differential
Permeability at ½-in. Pressure
150
140
130
120
110
100
80
70
65
60
55
50
45
.500
.550
.600
.650
.700
.750
.800
.850
Value of "K"

4. "K" Value Correlation

TABLE X demonstrates the correlation between "K" values which can be obtained among different samples and between different laboratories. The data listed as taken from TABLE VI and TABLE V are derived from tests made by the Materials Laboratory, Wright Air Development Center, on two different sets of samples. The data under TABLE VI were from an average of five tests and the data under TABLE V were from one test taken in a single marked area on a different set of samples from those examined under TABLE VI. The rank order correlation in this instance is .883.

The data from TABLE IV were established by the Contractor testing a 2-sq in. area over pressure differentials of 1/2 inch to 12 inches. The comparable data from TABLE V give the same samples, testing within the same marked area, but over only a 1-sq in. area, by the Materials Laboratory at Wright Field. These two columns show a rank order correlation of .921.

It is probable that the correlation between TABLE V and TABLE IV would be better if the Contractor had had available an instrument that could test up to 20-inch pressure differentials, and if the areas tested had been exactly the same, rather than only within the same 2-sq in. area.

Assuming that the data under TABLE VI (Average of Five Readings) are the most nearly correct of the three sets, the rank order correlation between this information and that shown in TABLE IV (one set of readings taken over a pressure differential range of only 1/2 to 12 inches of water) is still .895.

TABLE X

"K" VALUE CORRELATION

Code No.	"K" Values Derived from Data in: TABLE VI "K"	TABLE V "K"	TABLE IV "K"	Deviation TABLE V-VI	TABLE IV-VI	TABLE IV-V
1N	.624	.645	.630	.021	.006	-.015
2N	.605	.619	.642	.014	.037	.023
3N	.615	.619	.610	.004	-.005	-.009
4N	.579	.576	.578	-.003	-.001	.002
5N	.575	.582	.582	.007	.007	.000
6N	.582	.602	.600	.020	.018	-.002
7N	.665	.662	.692	-.003	.027	.030
8N	.609	.614	.610	.005	.001	-.004
9N	.613	.634	.630	.021	.017	-.004
10N	.605	.610	.621	.005	.016	.011
11N	.591	.625	.625	.034	.034	.000
12N	.591	.611	.605	.020	.014	-.006
1C	.740	.759	.793	.019	.053	.034
2C	.663	.656	.720	-.007	.057	.064
3C	.645	.647	.664	.002	.019	.017
4C	.622	.621	.629	-.001	.007	.008
5C	.658	.659	.730	.001	.072	.071
6C	.643	.642	.645	-.001	.002	.003
7C	.679	.710	.678	.031	-.001	-.032
8C	.597	.648	.640	.051	.043	-.008
9C	.626	.640	.635	.014	.009	-.005
10C	.660	.661	.666	.001	.006	.005
11C	.658	.654	.645	-.004	-.013	-.009
12C	.618	622	.641	.004	.023	.019
		Average Deviation		+.011	+.019	+.008

Rank Order Correlation:
TABLE VI & V - .883
TABLE VI & IV - .895
TABLE IV & V - .921

B. GENERAL COMMENTS

1. Weaving

No difficulty was experienced in connection with the producer's twist yarns in the warps of samples 1N through 6N and 1C through 6C. These trials seem to indicate that a fabric of this type made with 100 denier, 34 filament, Type 300 nylon warps could successfully be produced commercially with producer's twist in the warp yarns. This would not necessarily be equally true of lighter fabrics and other yarn sizes.

2. Finishing

Reproduction of identical permeability properties in reproduction lots was not accomplished merely by presumably making these lots in identically the same manner as the originals. Some reprocessing to readjust the permeability after initial finishing was resorted to, but did not fully accomplish the desired purpose. Exact control of permeability is not practical. A specification tolerance of not less than plus or minus 20% of the desired average is unavoidable.

3. Permeability Adjustments

(a) Calendering

The pressure used in calendering was the same for all of the calendered samples 1C through 12C and was relatively low pressure as compared to the capacity of the available machinery (7 tons used; 100 tons available). It is probable that all of the samples in this series could be made to yield the same permeability level merely by selecting the correct amount of pressure in the calendering of each. Furthermore, the permeability of the lowest of those shown can easily be reduced to much lower levels than those shown here (lowest, 1/2-in. water, 9 cu ft/sq ft/min; 20-in. water, 151 cu ft/sq ft/min).

(b) Twist

The amount of twist in yarns, and especially the filling twist, is again proven to be of major importance in establishing the permeability level. The addition of five turns per inch twist to the filling yarn alone results in doubling and tripling the permeability level. It is obvious therefore that variations in filling twist of as little as one turn per inch will result in significant variations in permeability. Twist variations of this magnitude are common and uncontrollable on even the most modern of commercial textile equipment. This again points up the fact that broad specification tolerances for permeability requirements are essential.

(c) Weave

These trials prove that weave does have a direct effect on permeability. The samples with plain (or taffeta) weave show the lowest permeability. The 2x1 twill and the dobby weave show a relatively slight difference. However, the number of binding points per square inch is approximately the same in both weaves and it seems evident that the permeability should not be too different.

C. CONCLUSIONS

No difficulty was experienced in producing fabrics which fell easily within the range of target properties. The data obtained seem to indicate clearly that it is possible to vary the air permeability characteristics at high and low differential pressures independently. In order to prove this finally and to establish limits, further experimental work is required, which was beyond the scope of this investigation.

The control of the value of the constant "K" is also a matter for further exploration, since the complete understanding of this control should greatly aid the designer of parachute fabrics in achieving his target properties.

APPENDIX I

MATHEMATICAL DEVELOPMENT

The following equations show the relationship of "K" to the concept "Effective Porosity" as described by Dr. Heinrich (1)*.

Symbols:

C	Effective porosity
ρ	Air density
V_1	Free stream velocity
V_2	Outflow velocity through fabric
M	Air permeability (cu ft/min/sq ft)
A	Air permeability at 1-inch pressure differential
K	Slope of line described above, a fabric constant
h	Pressure differential in inches of water
ΔP	Pressure differential in lbs/sq ft

(1) Empirical Formula - $\log M_n/M_x = K \log h_n/h_x$

(2) $C = V_2/V_1$

(3) $V_1 = \sqrt{2\Delta P/\rho}$

(4) $\Delta P = 5.2h$

(5) $V_2 = M/60$

(6) $V_1 = \sqrt{10.4h/\rho}$

(7) $C = V_2/V_1 = \frac{M}{60} \sqrt{\frac{\rho}{10.4h}}$

(8) $\log C = \log M + \log \frac{1}{60} \sqrt{\frac{\rho}{10.4h}}$

(9) $\log M/A = K \log h/1$

(10) $\log M = \log A + K \log h$

(11) $\log C = \log A + K \log h + \log \frac{1}{60} \sqrt{\frac{\rho}{10.4}} \sqrt{\frac{1}{h}}$

*APPENDIX III

$$(12) \quad \log C = \log \frac{A}{60} \sqrt{\frac{\rho}{10.4}} + (K - .5) \log h$$

$$(13) \quad C = \frac{A}{60} \sqrt{\frac{\rho}{10.4}} \times h^{(K - .5)}$$

Accordingly C will be constant (at constant air density) only if "K" equals 0.5. For values of "K" greater than 0.5, which is the general case, C will not be constant, but will follow the equation:

$$(14) \quad \log C_n/C_x = (K-.5)\log h_n/h_x$$

which is very similar to the original equation:

$$(1) \quad \log M_n/M_x = K \log h_n/h_x$$

differing only by the slope of the line representing this relationship. Obviously a change in the value of "K" will result in a greater proportional change in (K-.5). For example, a 20% increase in "K", from 0.600 to 0.720, would result in a change in (K-.5) from 0.100 to 0.220, an increase of 120%.

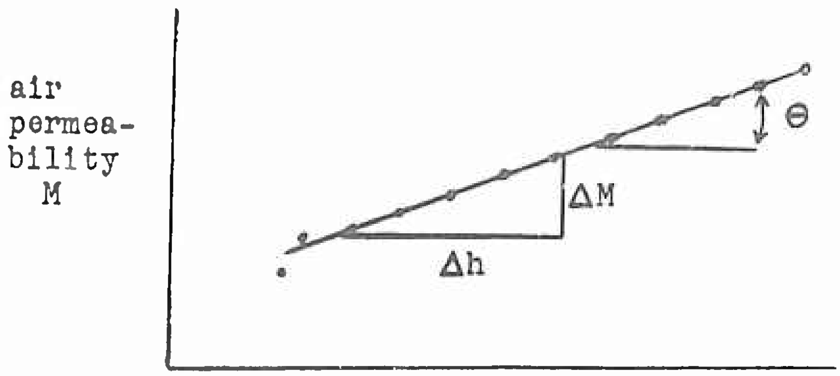
APPENDIX II

METHODS OF DETERMINING "K"

In the following methods for determining "K" it is assumed that readings of air permeability have been taken at several pressure differentials. It has been found as a general observation that the values of air permeability at pressure differentials above 2 inches of water more consistently lie on a straight line. At the lower pressure differentials of 1/2 inch and 1 inch, the points are apt to lie either above or below the best straight line for the rest of the points. For this reason, in calculating or otherwise measuring "K", it is best to disregard the lowest value obtained if it lies more than 10% away from the theoretical value given by the extrapolated straight line from the rest of the points. This results in the most accurate value of "K" for use in extending the line to pressure differentials higher than those measured. The following methods are suitable for determining "K":

A. Graphical Method

Plot values of air permeability vs. pressure differential on logarithmic graph paper. Draw the best representative straight line through the points plotted. The lowest points may not lie on this line (see above). Experience has shown that for other points which do not lie on the line, there is usually some explanation, as a typographical error or error in calculating air permeability.



(1) Measure ΔM and Δh. K equals $\Delta M/\Delta h$

or

(2) Measure the angle Θ with a protractor. $K = \tan\Theta$.

It is usually advisable to plot the points before going to either of the following mathematical methods of determining "K", since obvious errors which can easily be seen on a graph may not be picked up when only the figures are used.

B. Simplified or Short Form Method

Use values of air permeability obtained at any two pressure differentials such that the higher pressure is ten times the lower pressure. Subtract the logarithm of the lower air permeability from the logarithm of the higher air permeability. The answer is "K" directly. Best results are obtained if it is known from plotting that both points lie on the best straight line. Of the combinations $\frac{1}{2}$-5 inches, 1-10 inches, 2-20 inches, the latter is more likely to give accurate results for the reasons given above.

C. Method of Least Squares

"K" can be calculated very exactly, providing that the precautions outlined above are taken, that the points be plotted first, errors due to typography or prior calculations corrected, and the accuracy of the lower points be evaluated. Using the following symbolism:

h = pressure differential (any units)
M = air permeability (any units)
N = number of different readings used

$$K = \frac{\Sigma(\log h)(\log M) - \dfrac{(\Sigma \log h)(\Sigma \log M)}{N}}{\Sigma(\log h)^2 - \dfrac{(\Sigma \log h)^2}{N}}$$

APPENDIX III

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